Evaluation of Damage Characteristics

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Multifunctional Materials Branch

Mission – Scientific understanding and development of structural and functional materials, methods and devices for applications to components and systems.

- Focus on selected topic areas through interdisciplinary teams
- Materials of interest
    - Metals
    - Ceramics
    - Polymers
    - Composites
- Broad Range of spatial scales and time scales
- Integrated use of experimental and computational methods
- Link basic research to Navy, Marine Corps and DoD applications

Identifying Damage in Plates using Wavelets

Objectives

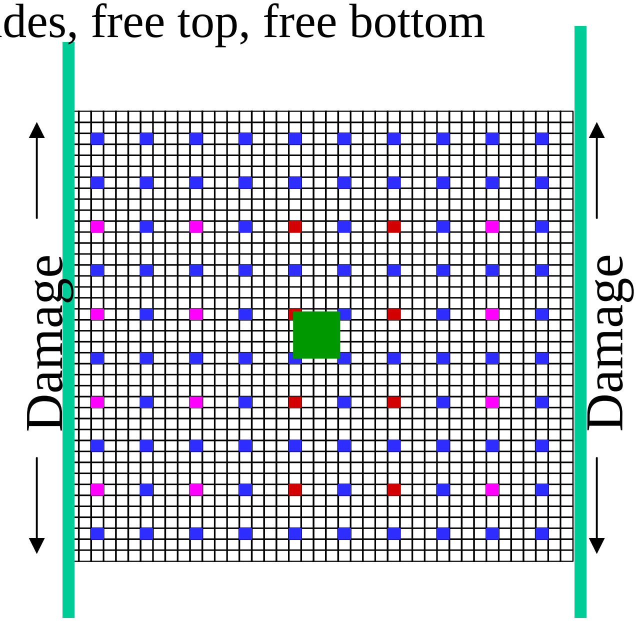
- Identify small amounts of damage in plate structures
- Determine optimum sensor placement on plate structures
- Determine robustness of wavelet approach

Approach

- Continuous Wavelet Transformation (CWT)
- Data from computational model or experiments
- Compare processed data of damaged structure to undamaged structure by extracting a feature of the sensor data

HY 100 Steel Plate (1 x 1 x 0.013 m)

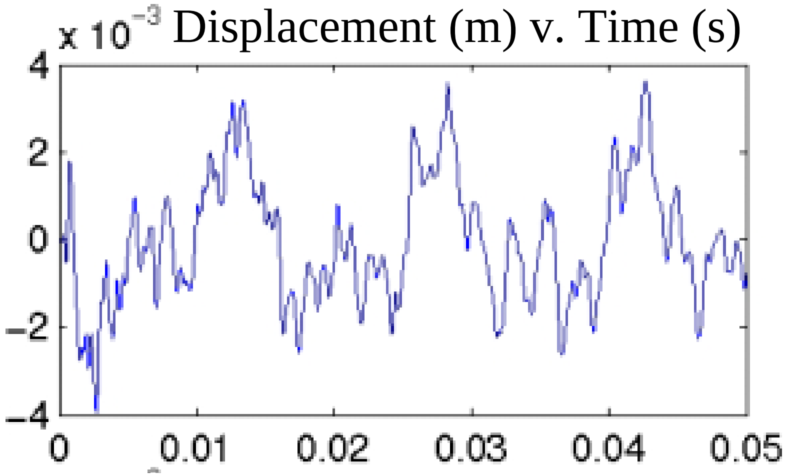
- Impulse load, out of plane, centered
- Fixed sides, free top, free bottom



Conclusions

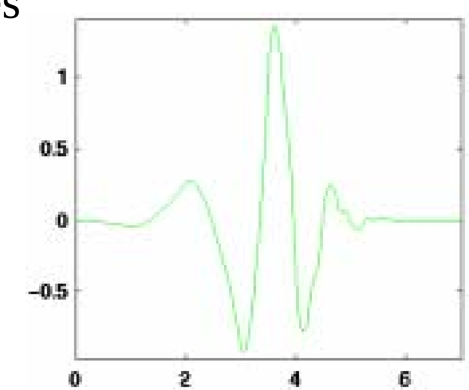
- CWT differences show damage evolution
- Higher wavelet scales include relevant information
- CWT difference not highly dependent upon wavelet type
- CWT difference most sensitive near high strain regions
- CWT difference not sensitive to normal amount of material variation
- CWT difference not sensitive to normal amount of temperature variation
- CWT sensitive to low amounts of damage

Continuous Wavelet Transforms (CWT)

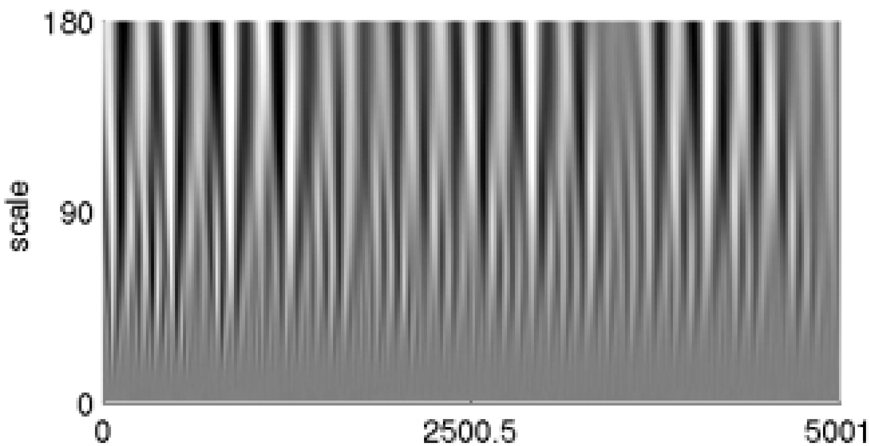


Square Homogeneous Plate

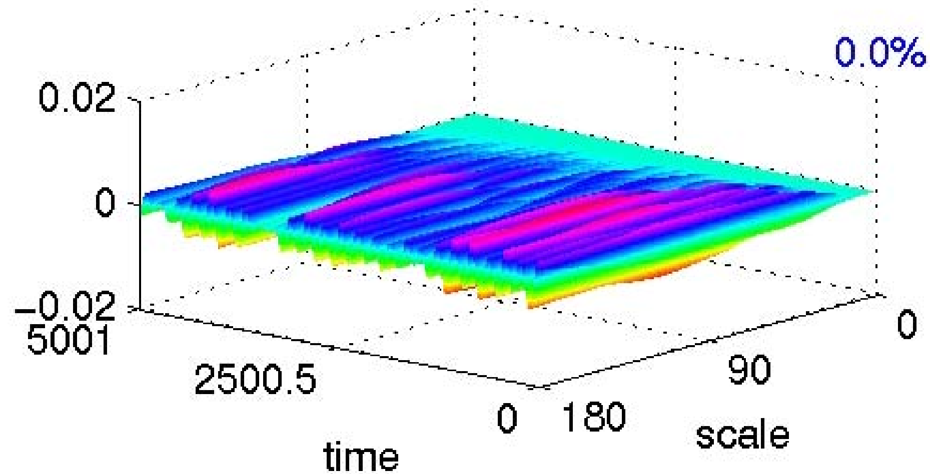
- 4^{th} Daubechies wavelet
- 180 wavelet scales
- 5001 steps
- Fixed sides
- No damage



Two Dimensional CWT Plot

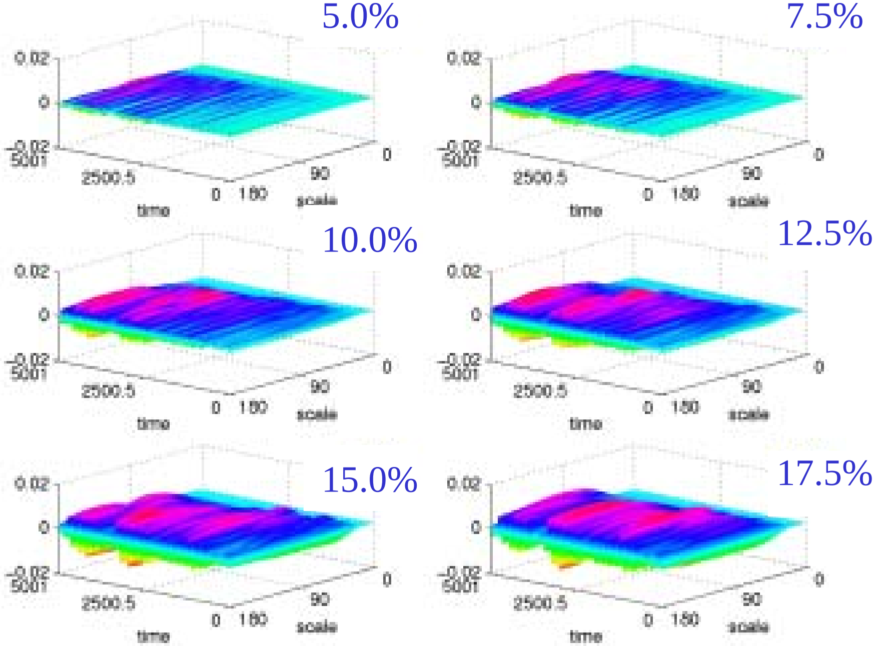


Three Dimensional CWT Plot

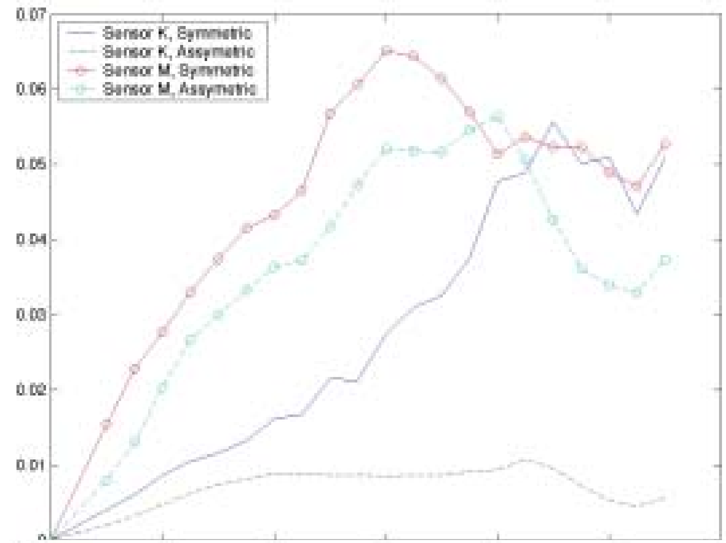


Differenced Continuous Wavelet Transforms (CWT)

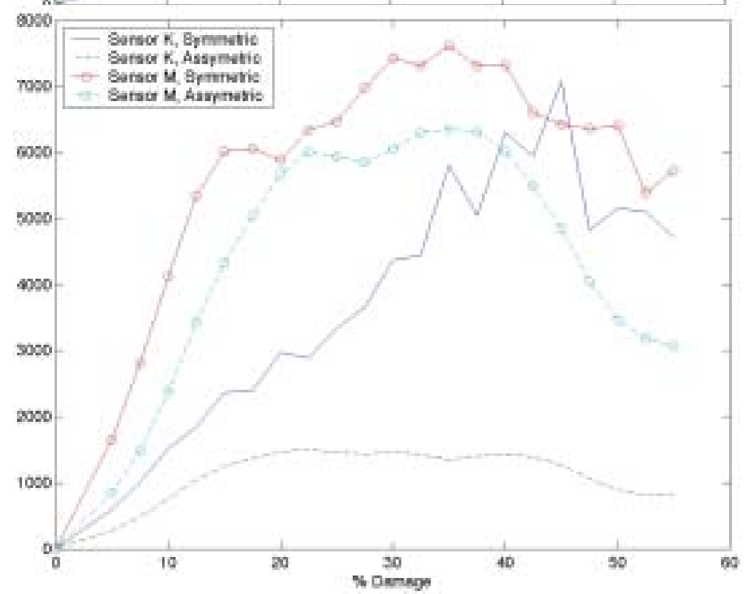
The undamaged CWT is subtracted from the damaged CWT



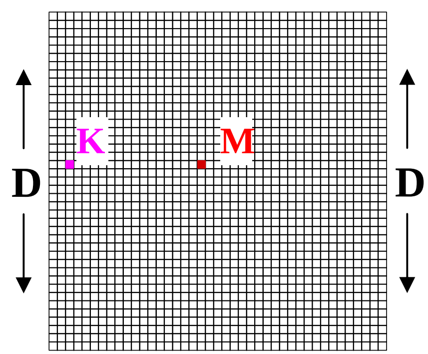
Maximum of the Absolute Values of Diff. CWT



Sum of Absolute Values of Diff. CWT



- Symmetric – Damage occurs on both sides
- Asymmetric – Damage occurs along the right side

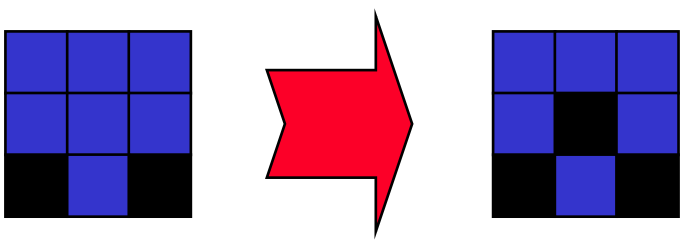


Microstructural Damage Evolution

Modeling Complex Damage Morphologies

Cellular Automaton Formulation With 2 Total Phases

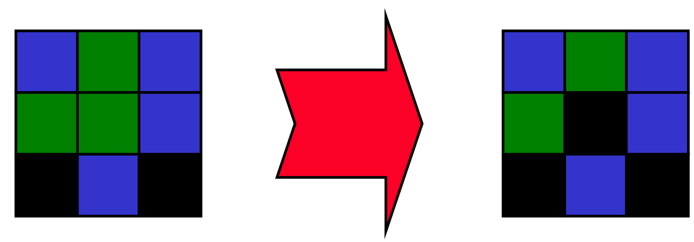
Material   Damage



- Cellular automaton formulation is a geometrically driven systems level approach for morphology evolution
- Previous results show that a wide range of damage morphologies can be generated from a single simulation architecture.
- Simulations are rapid and can support iterative systems ID methods

Cellular Automaton Formulation With 3 Total Phases

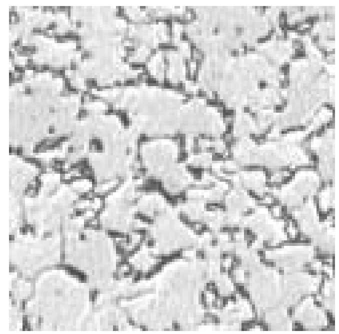
Material A   Material B   Damage



- 3-phase materials are important structural materials (ex. α/β titanium and composites)
- Cellular automaton parameters control
  - Plastic convection vs localized damage
  - Relative tendency to damage material A vs material B
  - Probability of a specific neighborhood changing to damage based on geometry and loading condition

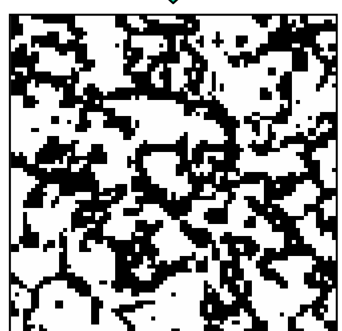
Image-Based Initial Conditions for 2 Phase + Damage Model

Titanium 64 alloy micrograph

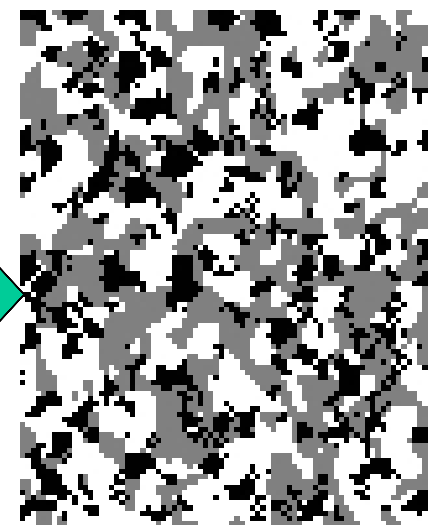


Cellular Automaton Parameters

- Material A more likely to develop damage than Material B
- Uniaxial loading conditions
- Microcrack rule tables

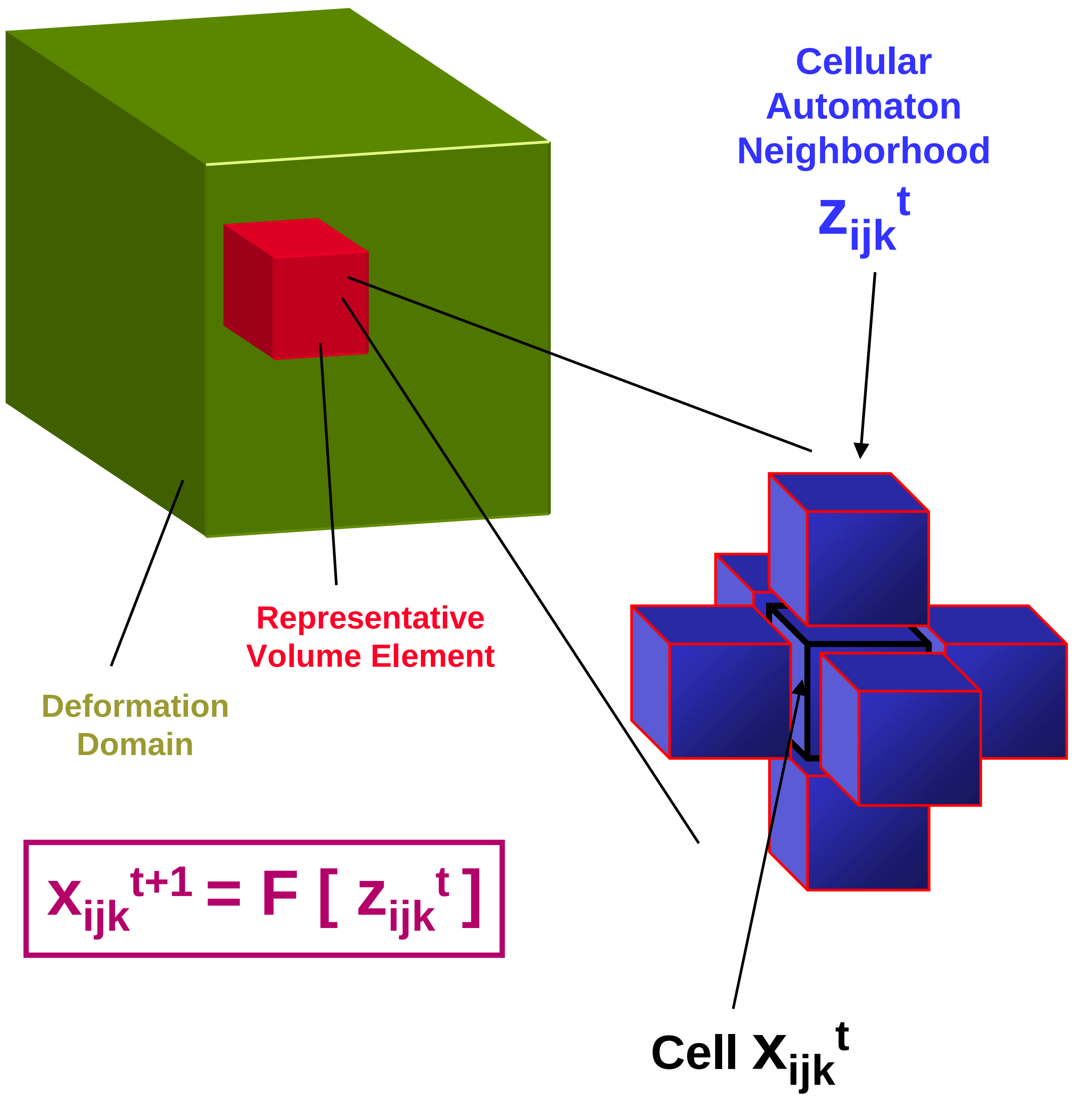


Binarized Model



Microstructural Damage Evolution

Modeling Complex Damage Morphologies



$$\boxed{x_{ijk}^{t+1} = F\,[\,z_{ijk}^{t}\,]}$$

3D Cellular Automaton Formulation

- Large possible number of distinct 3x3x3 neighborhoods requires new weighting schemes for rapid assessment.
- Evaluating reduced neighborhood using only nearest neighbors .
- Are there weighting schemes to handle larger neighborhoods needed for realistic 3D damage evolution?

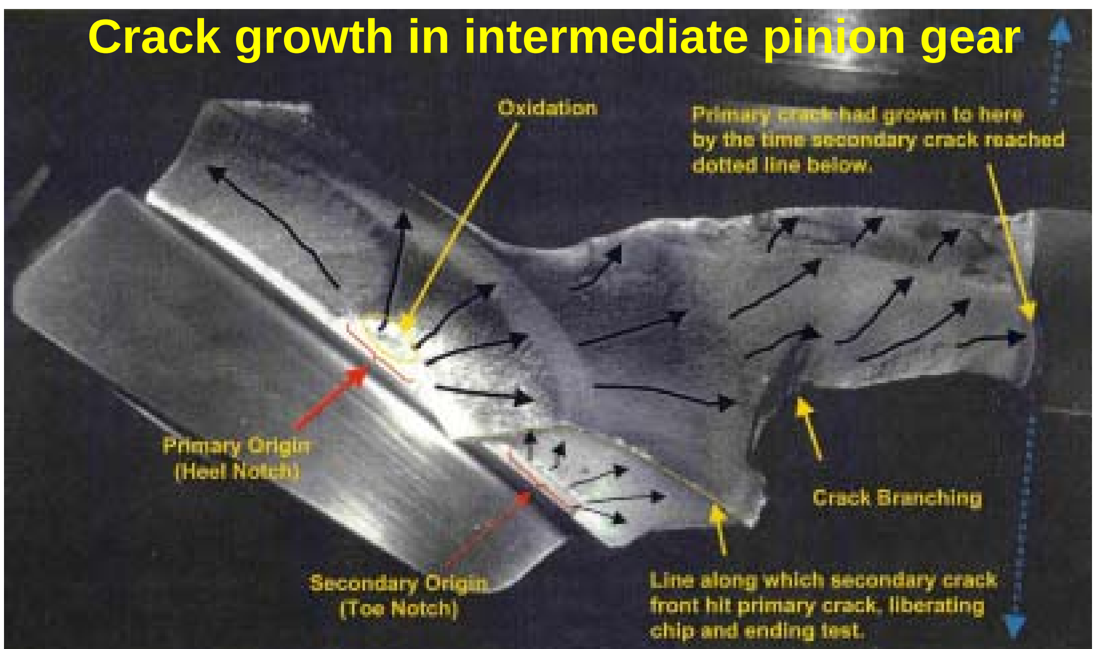
Evaluation of Helicopter Intermediate Gear Failure

<u>Objectives:</u> Prognosis of the impending failure of the H-60 intermediate input pinion gear and to be able to give an earlier warning of failure than currently possible.

<u>Approach:</u> Perform finite element model of cracked gear and measure changes of material generated magnetic field (proportional to the stress field in the ferromagnetic gear) to give an early warning of failure.

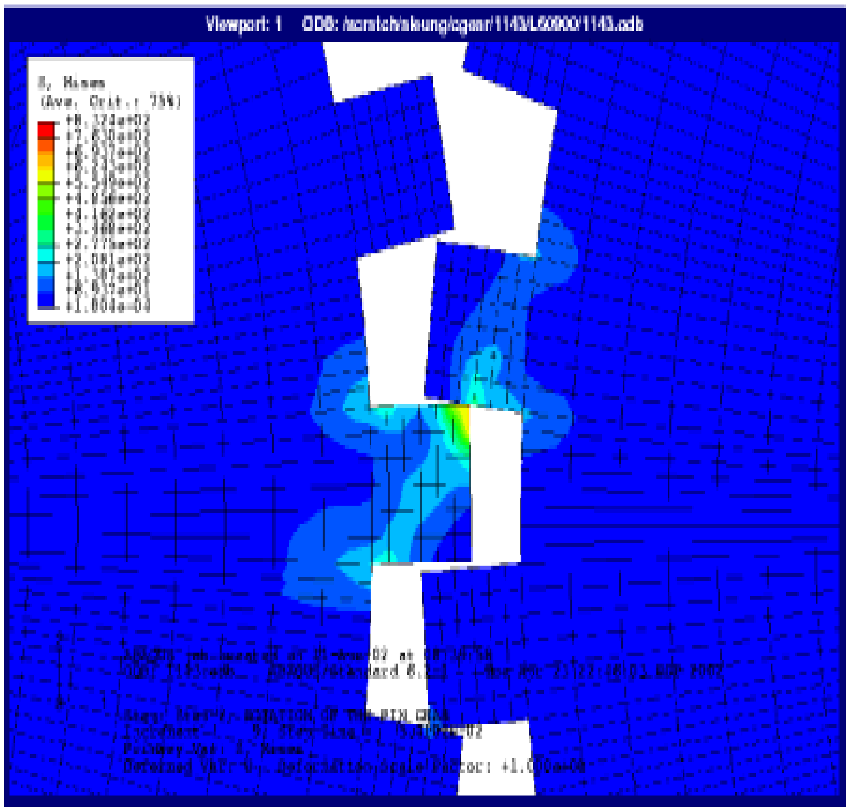
Gear Fatigue: Design Specifications

- Gear is composed of case hardened alloy steel
- Gear failure typically from fatigue
- Currently a warning of about three hours until catastrophic failure is determined by vibration changes. Unfortunately this is usually less than the flight time for a mission.
- Want an early warning of at least one mission.

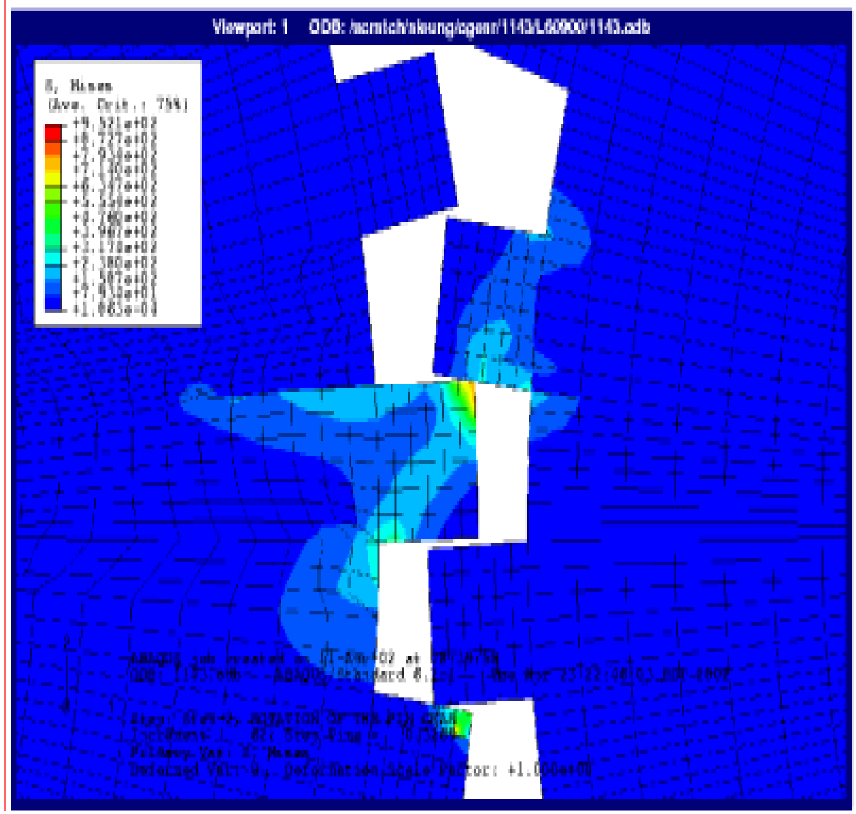


Finite Element Model of Gear: Stress

Gear stress *without* EDM'd crack

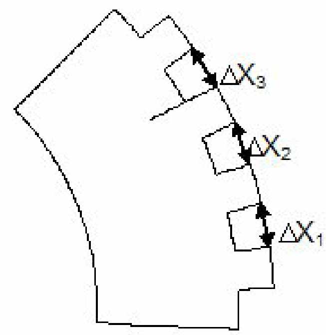


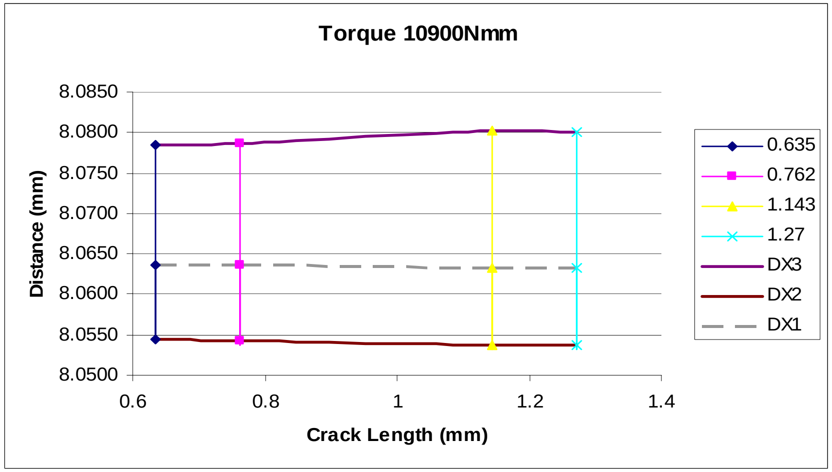
Gear stress with EDM'd crack

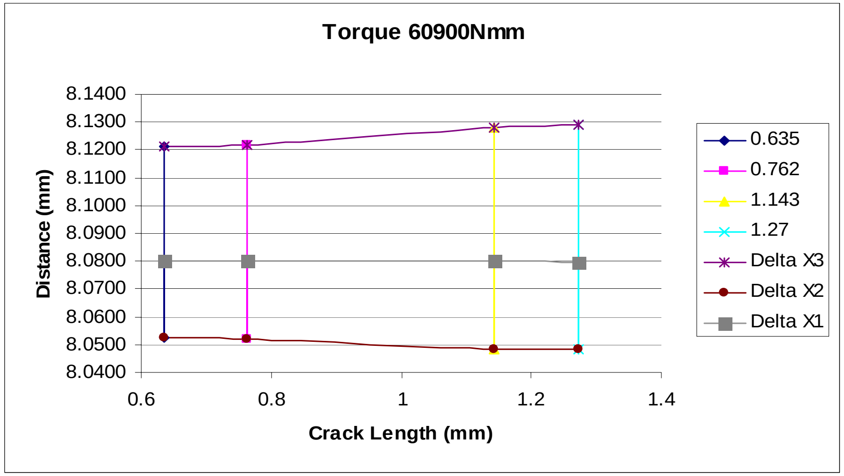


FE Model of Gear: Crack Lengths and Tooth Segments

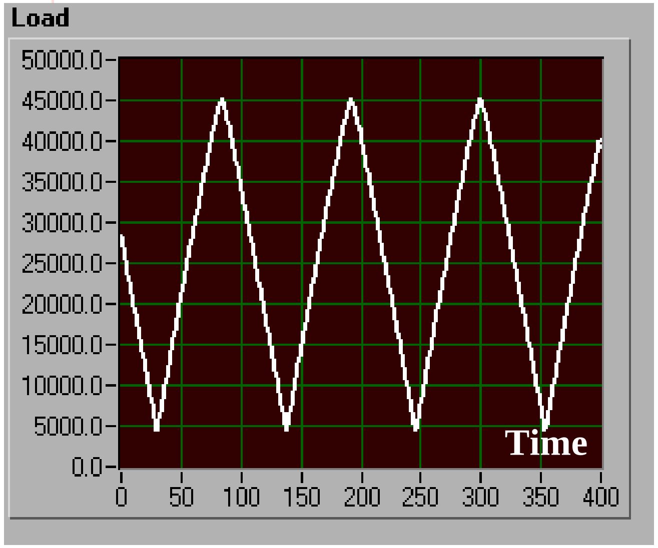
- Recognizable tooth displacements for low torques
- Highest tooth segment displacements at crack region
- Teeth displacements increasing with increasing crack length
- Applied torque affects tooth segment displacements more than crack lengths.

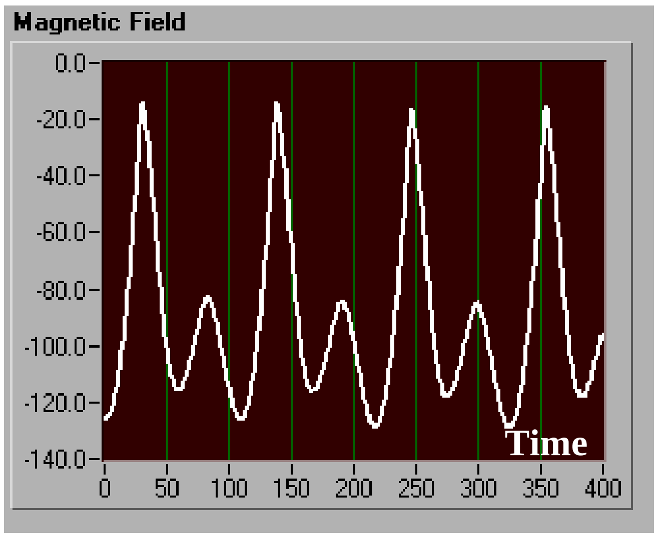






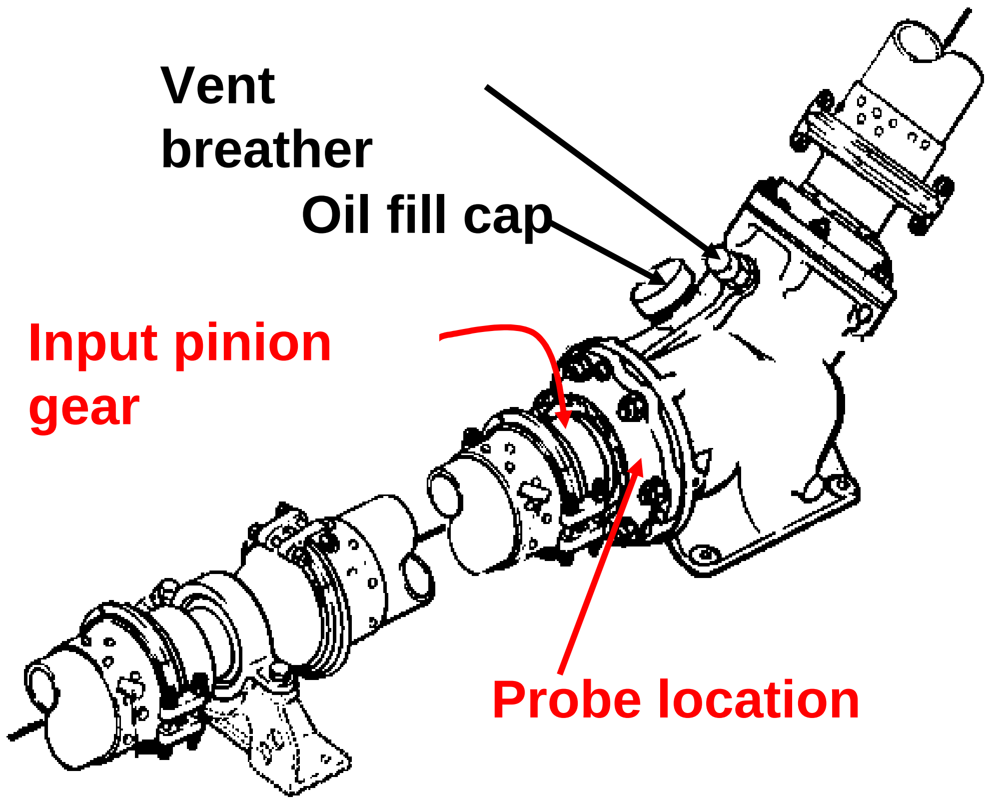
Measurement Physics and Gear/Probe Location



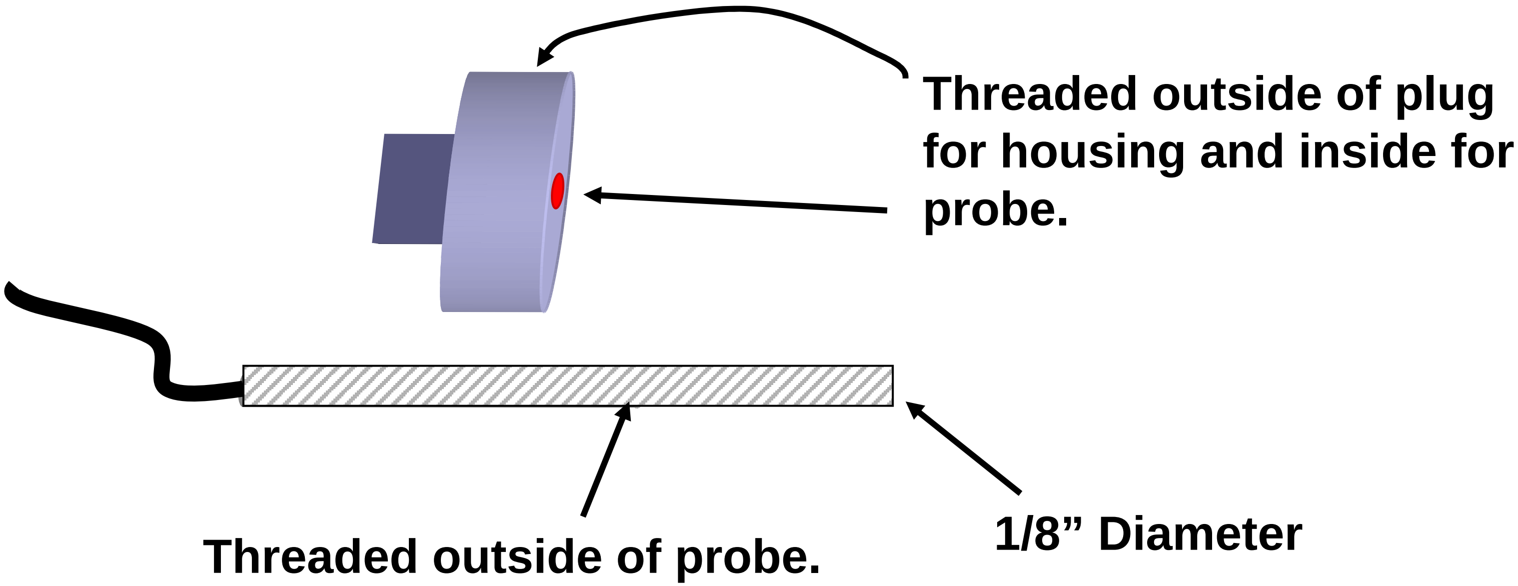


Magnetic field is a function of load.

Intermediate Gearbox



Measurement Probe and Method



- Digitize and capture data.
- Capture initial signal.
- Compensate for initial signal in order to increase monitoring sensitivity.
- Look for <u>change</u> in the magnetic signal.